Original Article

Comparative evaluation of frictional forces between ceramic brackets, metal insert ceramic brackets, and conventional metal brackets with three different arch wires: An *in vitro* study

ABSTRACT

Background: The aim of the study was to compare and evaluate the frictional resistance of clarity advanced ceramic brackets, metal insert ceramic bracket, and conventional metal brackets with Nickel–titanium wire and stainless-steel archwire of varying dimensions.

Materials and Methods: The sample size with 80% power was 45. The samples were divided into three groups each group consisting of 15, Group 1 – Clarity Advanced Ceramic Brackets (3M Unitek). Group 2 – Metal insert Ceramic Brackets (3M Unitek). Group 3 – Conventional Metal Brackets, the control group (3M Unitek). The wires used for testing were 0.016" Niti, 0.017 × 0.025" Niti and 0.019 × 0.025" SS.

Results: In the present study, it was found that wire material (nickel titanium) had an effect on friction. It was found that metal insert ceramic bracket exhibited similar frictional resistance when compared to metal brackets for 0.017 × 0.025" Niti and 0.019 × 0.025" SS wires. The Clarity Advanced bracket had the highest frictional resistance followed by metal insert ceramic and least with the conventional metal.

Conclusion: Clarity advanced can be the bracket of choice for the esthetically discerning patients who do not require extraction for orthodontic reasons, but the high frictional resistance in relation to larger rectangular Niti archwires should be considered. In adult patients who require extraction in the treatment plan, metal insert ceramic brackets are definitely a pleasing alternative when compared to metal brackets.

Keywords: Archwire-bracket slot, frictional resistance, metal insert ceramic brackets

INTRODUCTION

In orthodontics, space closure is often undertaken using friction mechanics. Some of the applied force is dissipated as friction, and hence it is important to know the actual amount of force required to obtain an optimal biological response. Friction is the resistance to motion when one object moves tangentially against another.[1] Most fixed appliances techniques involve some degree of the impact sliding between bracket and archwire; whenever sliding occurs, frictional resistance is encountered.

Tooth movement associated with sliding mechanics has been described as a series of short steps involving tooth tipping and uprighting, rather than a continuous, smooth, and gliding movement. The overall resistance to sliding in orthodontic appliances is a combination of classical friction, archwire-bracket binding, and archwire notching. At a minimal bracket-archwire angulation and torque, friction is mainly due to classical friction, whereas binding and notching become more prominent at large bracket-archwire angulations.[2] The proportion of the applied force that is

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actually transmitted into tooth movement decreases. This results in a less efficient orthodontic mechanotherapy.

Ceramic brackets were introduced in 1980 by Wallshein and Rushell,[3] and it has gained increased acceptance and adult patients prefer this esthetic alternative to metal brackets. Ceramic bracket technology has evolved rapidly. Studies[4] have shown that stainless steel (SS) brackets have reduced levels of friction relative to ceramic brackets. Angolkar *et al*.[5] performed an *in vitro* study to determine the frictional resistance offered by ceramic brackets used in combination with wires of different alloys and size during translatory movement of brackets.

Higher friction during sliding mechanics is an important concern in the use of ceramic brackets.[3] Clinically, both static and kinetic frictions are important. A number of factors determine the friction generated, like the bracket material, the surface area, the surface texture etcetera. Ceramic brackets are associated with several problems, increased frictional resistance in sliding mechanics being one of them. To overcome this drawback, metal insert ceramic brackets were introduced recently which claim to have decreased frictional resistance.

During sliding mechanics, the orthodontic force applied should exceed the frictional force (FF) between bracket and archwire to allow tooth movement.[6] If the FF is high, then the orthodontic force applied should be higher to overcome friction and excessive force would be deterrent to the periodontal tissues and cause hyalinization. Hence, there would be undue delay in orthodontic treatment.

Friction is an important factor in determining the rate of tooth movement at all stages of mechanotherapy including alignment, leveling, and space closure. From existing literature,[2-4] it is brought to light that the bracket material and the wire material account for the frictional resistance. It is well established that two metal surfaces offer lesser frictional resistance as compared to ceramic surface against metal.[3] Hence, metal inserts have been incorporated into the slot of ceramic brackets, in order to reduce friction. Research involving these newer brackets is scarce. Hence, the aim of the study was to compare and evaluate the frictional resistance of clarity advanced ceramic brackets, metal insert ceramic bracket, and conventional metal brackets with nickel–titanium wire and stainless-steel archwire of varying dimensions.

MATERIALS AND METHODS

The sample size calculation, for this *in vitro* study, was based on the statistical evaluation of the parent study[1] with 80% power, with the total sample size of 45. The samples were divided into three groups, each group consisting of 15 samples. Group segregation was as follows:

- Group 1 – Conventional Metal Brackets, the control group (3M Unitek)
- Group 2 – Metal insert Ceramic Brackets (3M Unitek)
- Group 3 – Clarity Advanced Ceramic Brackets (3M Unitek).

In the abovementioned brackets, three types of archwire segments were tested; 0.016" NiTi (3M Unitek), 0.017" × 0.025" NiTi (3M Unitek), and 0.019"' × 0.025" SS (3M Unitek) straight length wire. Archwire was ligated to the bracket slot with 0.010 inch SS ligature. All brackets used in this study were maxillary first premolar brackets 0.022" × 0.028" slot size, MBT prescription.

A commercially available 4 × 2 inch acrylic plate was used to mount the brackets. At one end of the plate, a horizontal and vertical line was drawn; a point of intersection of these two lines was taken as a point of bracket placement. Brackets were stabilized by means of an industrial adhesive. Universal testing machine was used with 5 kg load cell to determine the FF. The testing apparatus constructed of SS was designed to hold the bracket during the mechanical test [Figure 1]. The machine was adjusted in the tensile mode, and the force levels were measured in Newton's in a digital read out. The testing machine not only measured the tensile force required to pull the wire through fixed bracket but also gave the tracking distance as a digital read out in length of millimeters as the cross head travelled superiorly up the wire.

A wire of about 15 cm length is taken and placed in the bracket and ligated with SS ligatures twisted until taut and untwisted quarter turn. The other end of the acrylic plate was mounted on to the lower grip of universal testing machine. The free end of the archwire was fixed to the upper grip of

Figure 1: Universal test machine with the sample mounted for testing

the universal testing machine which was connected to the load cell. Each wire was pulled through the bracket slot by a distance of 7 mm at a speed of 5 mm/min, the force levels were recorded in Newton's (1 Newton $n = 102$ g) from the digital marker.

Fifteen archwires in each group and the 15 brackets were tested such that a new bracket and wire is used for every test in each group and then discarded and a fresh ligation is used for each ligation, this was done in order to eliminate the influence of dimensional changes. All the tests were done in dry condition. Friction resistance of 0.022" × 0.028"slot conventional SS bracket, Metal insert ceramic bracket, and clarity advanced ceramic bracket against three archwires were determined and tabulated.

RESULTS

The tabulated data were analyzed, and statistical analysis was performed. The data distribution was found to be normal as tested by Kolmogorov–Smirnov test. ANOVA was done to compare the difference in friction between the three groups [Tables 1-3]. Bonferroni *post hoc* test was done to find out the inter group differences [Tables 4-6].

In Group 1, there was a significant difference between the wires; indication there was maximum frictional resistance offered in 0.019 × 0.025" SS wire, followed by 0.017 × 0.025" Niti and 0.016" Niti being the least. There was statistically significant reduction of friction for 0.016" Niti wire when compared to other two wires. This may be attributed to the round configuration of the wire [Tables 1, 4 and 7].

In Group 2, there was no significant difference in levels of friction between the three wires, when used with metal insert ceramic bracket indicating there was lesser and similar amounts of frictional resistance [Tables 2, 5 and 8].

In Group 3, there was a significant difference in friction between the wires with ceramic brackets, indicating 0.017 × 0.025" NiTi wire had the most frictional resistance, followed by 0.019 × 0.025" SS and 0.016" NiTi wire having the least. NiTi rectangular wire offered the most resistance; this may be attributed to the binding effect of NIti [Tables 3, 6 and 9].

There was no significant difference between the groups with 0.016" Niti wire. It is important to note that frictional resistance offered by metal insert ceramic brackets were not significantly higher when compared to metal brackets, and they were much lower to a significant level when compared to ceramic brackets. The same findings were seen in the brackets with 0.019 × 0.025" SS wire as seen in Graph 1.

Table 1: ANOVA for frictional resistance of metal bracket with archwires

ANOVA FRICTION RESISTANCE (in newton)					
	Sum of Squares	Df	Mean Square	*F*	Sig.
Between Groups	28.390	2	14.195	8.886	0.001
Within Groups	67.094	42	1.597		
Total	95.484	44			

Table 2: ANOVA for frictional resistance of metal insert bracket with three archwires

ANOVA FRICTION RESISTANCE (in newton)					
	Sum of Squares	Df	Mean Square	*F*	Sig.
Between Groups	10.333	2	5.166	1.895	0.163
Within Groups	114.478	42	2.726		
Total	124.811	44			

Table 3: ANOVA for frictional resistance of metal insert ceramic bracket with three archwires

ANOVA FRICTION RESISTANCE (in newton)					
	Sum of Squares	Df	Mean Square	*F*	Sig.
Between Groups	54.822	2	27.411	7.073	0.002
Within Groups	155.017	40	3.875		
Total	209.839	42			

DISCUSSION

Friction is the resistance to motion when one object moves tangentially against another. The coefficient of friction for a given material surface is a constant, which may be dependent on the roughness, texture, or hardness of the surfaces. The actual FF is the product of the coefficient of friction and the normal force. In order for one object to slide against the other, the orthodontic force application must overcome the FF.[7]

High levels of FF between the bracket slot and the archwire might cause binding between the two components; this in turn results in little or no tooth movement. Furthermore, binding during retraction of the anterior teeth can lead to loss of anchorage. Friction can also exist during the initial leveling and alignment stage when an archwire slides through the bracket slots and tubes. Therefore, it is essential to understand the effect of friction between the bracket and the archwire on tooth movement so that the proper force can be applied to obtain adequate tooth movement and optimum

Table 4: *Post hoc* comparison for values obtained for metal brackets

Multiple comparisons Dependent variable: FRICTION RESISTANCE (in newton) bonferroni					
(I) Bracket (J) Bracket	Mean Difference (I-J)	Std. Error	Sig.	95%confidence interval	
				Lower bound	Upper bound
0.016 NITI 17×25NITI	-1.5925000	0.46151638	0.004	-2.7433683	-0.4416317
19×25NITI	-1.7642120	0.46151638	0.001	-2.9150803	-0.6133437
17×25NITI 0.016NITI	1.59250000	0.46151638	0.004	0.4416317	2.7433683
19×25NITI	-0.17171200	0.46151638	1.000	-1.3225803	0.9791563
19×25SS 0.016NITI	1.76421200	0.46151638	0.001	0.6133437	2.9150803
17×25NITI	0.17171200	0.46151638	1.000	-0.9791563	1.3225803

Table 5: *Post hoc* comparison for values obtained for metal insert ceramic brackets

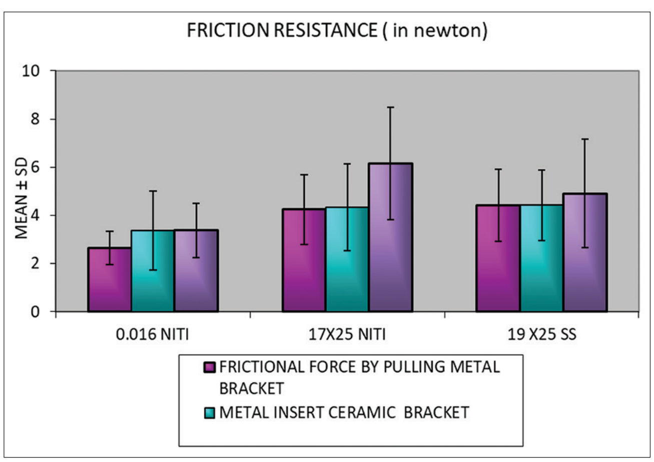
Multiple comparisons Dependent variable: FRICTION RESISTANCE (in newton) bonferroni					
(I) Bracket (J) Bracket	Mean Difference (I-J)	Std. Error	Sig.	95%confidence interval	
				Lower bound	Upper bound
0.016 NITI 17×25NITI	-97084000	0.60284605	0.344	-2.4741375	0.5324575
19×25NITI	-1.0567000	0.60284605	0.261	-2.5599975	0.4465975
17×25NITI 0.016NITI	-97084000	0.60284605	0.344	-0.5324575	2.4741375
19×25NITI	-0.08586000	0.60284605	1.000	-1.5891575	1.4174375
19×25SS 0.016NITI	1.05670000	0.60284605	0.261	-0.4465975	2.5599975
17×25NITI	0.08586000	0.60284605	1.000	-1.4174375	1.5891575

The mean difference is significant at 0.05 level

Table 6: *Post hoc* comparison of values obtained for ceramic brackets

Multiple comparisons Dependent variable: FRICTION RESISTANCE (in newton) bonferroni					
(I) Bracket (J) Bracket	Mean Difference (I-J)	Std. Error	Sig.	95%confidence interval	
				Lower bound	Upper bound
0.016 NITI 17×25NITI	-2.7911855	0.74596977	0.002	-4.6552564	-0.9271146
19×25NITI	-1.5364580	0.71883445	0.116	-3.3327217	0.2598057
17×25NITI 0.016NITI	2.79118554	0.74596977	0.002	0.9271146	4.6552564
19×25NITI	1.25472754	0.74596977	0.301	-0.6093434	3.1187984
19×25SS 0.016NITI	1.53645800	0.71883445	0.116	-0.2598057	3.3327217
17×25NITI	-1.2547275	0.74596977	0.301	-3.1187984	0.6093434

The mean difference is significant at 0.05 level



Graph 1: Comparison of mean frictional resistance for all three brackets and archwires types

biologic response and/or to avoid the precipitating factors which cause friction.[6]

There are two types of friction, static and kinetic. Static friction is opposed to any application of force, and its magnitude is exactly that which would prevent movement between two surfaces: kinetic friction is opposed to the direction of movement of the object and occurs when the bodies are in motion.[8]

The FFs acting at the bracket archwire interface are due to the complex interaction of various factors. Several variables exist that can directly or indirectly contribute to the FF levels between the bracket and the wire. The factors include such as archwire, active torque, thickness, cross-sectional shape and size of the archwire ligature type, and force; material, width of the bracket; inter bracket distance, level of bracket slots between adjacent teeth, forces applied for retraction, bracket wire angulations, and point of force application.[9]

One factor which can be controlled by the orthodontist is the choice of bracket material. Previous studies have indicated

Table 7: Descriptive statistics for metal bracket with three archwires

Descriptives Friction resistance (in newtons)								
	n	Mean	Std.deviation	Std.error	95% confidence interval		Minimum	Maximum
					Lower bound	Upper bound		
0.016NITI	15	2.6520860	0.68763885	0.17754759	2.2712843	3.0228877	1.59375	3.54688
17×25NITI	15	4.2445860	1.44224097	0.37238502	3.4458996	5.0432724	1.70313	6.64063
19×25SS	15	4.4162980	1.49650747	0.38639657	3.5875598	5.2450362	1.18750	6.82813
Total	45	3.7709900	1.47312360	0.21960030	3.3284147	4.2135653	1.18750	6.82813

Table 8: Descriptive statistics for metal insert ceramic brackets

Descriptives Friction resistance (in newtons)								
	n	Mean	Std.deviation	Std.error	95% confidence interval		Minimum	Maximum
					Lower bound	Upper bound		
0.016NITI	15	3.3635440	1.64555421	0.42488027	2.4522665	4.2748215	1.34375	8.00000
17×25NITI	15	4.3343840	1.81756576	0.46929346	3.3278496	5.3409184	2.34375	8.28125
19×25SS	15	4.4202440	1.47160852	0.37996769	3.6052944	5.2351936	2.03125	8.00000
Total	45	4.0393907	1.68422456	0.25106937	3.5333936	4.5453877	1.34375	8.28125

Table 9: Descriptive statistics for metal insert ceramic brackets

Descriptives Friction resistance (in newtons)								
	n	Mean	Std.deviation	Std.error	95% confidence interval		Minimum	Maximum
					Lower bound	Upper bound		
0.016NITI	15	3.3770860	1.13521161	0.29311038	2.7484268	4.0057452	1.67188	5.43750
17×25NITI	15	6.1682715	2.33704764	0.64818039	4.7560078	7.5805353	2.04688	9.18750
19×25SS	15	4.9135440	2.25884793	0.58323203	3.6626357	6.1644523	2.28125	9.75000
Total	45	4.7569065	2.23520989	0.34086631	4.0690104	5.4448026	1.67188	9.75000

that SS bracket have an advantage of having the least friction. They are widely used as it is economical and corrosion resistant but stainless-steel brackets are not esthetic and it may be a matter of concern for adult patients.[10]

In clinical use, the problems encountered with the use of ceramic brackets included brittleness, leading to bracket or tie-wing failure, iatrogenic enamel damage during debonding, enamel wear of opposing teeth, and high frictional resistance to sliding mechanics.[1]

Recently, polycrystalline ceramic brackets having metal-lined archwire slot were introduced to the market in an attempt to minimize some of the problems that were encountered by the clinician. The advantage of having a stainless-steel slot is to minimize the increased friction that occurred as a result of the archwires contacting the ceramic surface. Up to 60% of the force applied for dental movement can be lost as the result of ceramic bracket resistance to sliding, leading to a longer treatment period.[11]

Clarity advanced is a recently developed ceramic bracket. The size of this bracket is comparatively smaller without compromising bracket strength. These brackets are constructed of a fine-grained material that is stronger than the material used in Clarity Metal-Reinforced Brackets, so a metal liner is not needed to provide additional strength. Clarity advanced ceramic brackets are injection molded, providing rounded corners in the slot, which the manufacturers claim to potentially reduce binding and notching in the bracket slot.[12]

The effect of metal insertion in the slot of ceramic bracket on frictional resistance offered against archwires, which vary in dimension and composition, has not been studied so far. Therefore, the purpose of this study was to evaluate and compare the frictional resistance of metal bracket (Gemini 0.022" slot MBT; 3M UNITEK), metal insert ceramic bracket (clarity TM), and Clarity advanced ceramic bracket with 0.016"niti, 0.017 × 025"Niti and 0.019 × 0.025" SS wires. These three archwires were selected because they are the most commonly used in the clinical scenario.

The results of this study showed that the highest frictional resistance among the brackets was seen with the Clarity advanced, followed by Clarity and the least with the conventional metal bracket [Tables 7-9], but the values were statistically significant only with the 0.017 × 0.025" Niti archwires. This outcome was similar to a study done by

Cacciafesta *et al*., who concluded that ceramic brackets had higher frictional resistance compared to metal brackets.[1] In addition, it was found that there was no difference in the frictional resistance between metal brackets and metal insert ceramic brackets in all the three archwire combinations. This finding is contradictory to the finding of Cacciafesta *et al*. Result of the present study shows that metal insert ceramic brackets are fitting alternatives to ceramic brackets in esthetically inclined adult patients requiring extraction of premolars for orthodontic therapy because there would be less friction during sliding mechanics when compared to ceramic bracket.

With the Clarity advanced bracket, 0.017 × 0.025” NiTi had the highest friction followed by 0.019 × 0.025” SS [Table 3] and 0.016 NiTi [Tables 3, 6 and 9]. The increase in FF for 0.017 × 0.025” NiTi and ceramic bracket combination may be due to the binding effect of titanium in the nickel titanium alloy with ceramic slot as observed by Michelberger *et al*.[2] Since the. 016” NiTi had a smaller surface area in contact, they had the least amount of friction. This was similar to the studies done by Vaughan *et al*. and Downing *et al*.[13,14]

With conventional metal bracket, there was a statistically significant difference in friction between 0.016” nickel–titanium [Tables 1 and 7] and other wires. 0.016” NiTi has very low levels of friction with metal bracket than either 0.017 × 0.025” NiTi or 0.019 × 0.025” SS wires. This correlated with the study of Nishio *et al*.[6] which concluded that the increasing thickness of the wire produces greater FF values than the round wires, because there is a larger contact area between slot and wire surfaces. However, thinner wires could increase the bracket-wire angulation and consequently increase the FF.[6,15-17]

In metal insert ceramic brackets, there was no statistically significant difference in friction between the three archwires [Tables 2, 5 and 8]. They showed reduced value of FF when compared to ceramic bracket because its slot is reinforced with metal which prevents the direct contact between ceramic and wire. The SS bracket had less friction compared to metal insert ceramic brackets [Tables 7 and 8], but this was not statistically significant, because of the characteristics of SS which allows better polishing and a smoother surface. The results of the study imply that insertion of metal slot in ceramic bracket nullifies the increase in friction commonly associated with ceramic bracket.

Previous studies[16,17] have investigated some of the variables that are thought to influence the FF at the bracket/archwire interface. Pizzoni *et al*.[18] found the selection of bracket design, wire material, and wire cross section to significantly influence the forces acting in a continuous arch system.

In the present study, it was found that wire material (nickel titanium) had an effect on friction. Friction with NiTi wire was increased with ceramic bracket than for metal or metal insert bracket. Overall the frictional resistance was highest with the Clarity Advanced and with 0.017 × 0.025” NiTi combination, followed by the Clarity Advanced and 0.019 × 0.025”SS. The least frictional resistance was found with the conventional metal bracket and 0.016” NiTi.

Esthetics in the choice of brackets is a major concern for adult patients and many a times orthodontists are stuck in a dilemma when adult patients require extraction. Metal inserted ceramic brackets are an excellent choice in such patients because of decreased friction during sliding, whereas simple non extraction therapy can be performed using ceramic brackets.

Although there is a decisive conclusion with regard to treatment planning, the present study is an *in vitro* study and additional research like evaluating the rate of retraction in the same brackets is necessary.

CONCLUSION

The following conclusions were derived from the study:

1. The Clarity advanced bracket had the highest frictional resistance followed by metal insert ceramic and least with the conventional metal, but it was statistically significant only with the 0.017 × 0.025” NiTi archwire
2. Among the archwires, 0.016” NiTi had the least friction with all the three brackets
3. Clarity advanced can be the bracket of choice for the esthetically discerning patients who do not require extraction for orthodontic reasons, but the high frictional resistance in relation to larger rectangular NitT archwires should be borne in mind
4. In adult patients who require extraction in the treatment plan, metal insert ceramic brackets are definitely a pleasing alternative when compared to metal brackets.

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Conflicts of interest

There are no conflicts of interest.

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